DESIGN OF A REINFORCED CONCRETE ARCH

J. A. MEGAHY

ARMOUR INSTITUTE OF TECHNOLOGY

1909

Megahy, James A.
Design of a reinforced
concrete arch

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Design of a Reinforced Concrete Arch

A THESIS

.... PRESENTED BY ....

James A. Megahy

... TO THE ...

PRESIDENT AND FACULTY

OF THE

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

Bachelor of Science in Civil Engineering

Having Completed the Prescribed Course of Study in Civil

ENGINEERING

APRIL 1ST 1909

Alfred E Phillips
Prof Civil Engineering

H. M. Raymond
Dean of Eng Studies

L. C. Monin
Dean of Cult. Studies.

" THESIS."

" THE DESIGN OF A REINFORCED CONCRETE ARCH OF 80' SPAN."

The arch is to have a total width of 38ft., 22 ft. for roadway and two 8 foot cement sidewalks. The live load is to be 100 lbs per sq. ft. and provision is to be made for street car traffic.

LOADING:- The car track occupies a width of 16 2/3 ft. and the live load per linear foot of track 1800 p er sq.ft. Remaining floor surface 160 lbs per sq.ft. including sidewalks.

DEAD LOAD:- Concrete 150 lbs per cu.ft.
Earth fill 120 " " " "
Pavement 12"deep 150 lbs per cu.ft.
Car track 25 lbs per sq.ft.

LIVE LOAD:- 1800 lbs per linear ft. of bridge over 16 2/3" width
100 " "sq.ft. for remainder of floor surfac e.

" METHOD OF DESIGN."

The method used is that of Prof. Cain, with the construction of the deflection polygons from Prof. Burr's "Stresses in Bridge and Roof Trusses." The methos of finding the summations by tabulation is due to Mr. Thacher. In the design of an arch, the method consists in finding the true equilibrium polygon for any system of loading and its true position in the arch ring. The conditions which, when fulfilled, give the results are (I) that the tangents to the neutral line of the ring at the springing are fixed in direction (2) that the span is invariable; and (3) that the vertical deflection of one springing line with respect to the other is zero.

Expressed mathematically, these conditions are:

$$\sum \frac{Ms}{EI} = 0;$$

$$\sum \frac{Mys}{EI} = 0;$$

$$\sum \frac{Mxs}{EI} = 0;$$

in which (s) is the length of a small division of segment of the ring measured on the neutral line and (y) and (x) are, respectively, the ordinate and absissa of the center of (s) with the origin at one springing; For a reinforced concrete ring these equations of condition take the form

$$\sum \frac{Ms}{E_c(I_c+eI_s)}=0; \quad \sum \frac{Mys}{E_c(I_c+eI_s)}=0; \text{ and } \sum \frac{Mxs}{E_c(I_c+eI_s)}=0;$$

Let H = horizontal thrust, which is constant throughout the ring for any given loading.

t the intercept of the ordinate between the neutral axis and the line of pressure.

$M=Ht$, and $e=E_s/E_c$ practically constant throughout, then if we make $s\div(I_c+eI_s)$ constant by construction $\frac{Hs}{E_c(I_c+eI_s)}$ may be placed outside of the sign of summation and we have ,

$\sum t=0$, $\sum ty=0$, and $\sum tx=0$

$I_c\div I_s$ is constant throughout the ring, therefore making $s\div I_c$ constant fulfills the condition.

Since $I_c=b'h^3\div 12$, where (b') is the thickness of the slice of the ring considered, usually 12 inches and (h) is the radial depth of the ring we may construct $s\div h^3$ constant.

The rise (r) was made 1/8 of the span or 10 feet.

The radius of the center line=(R)= $\frac{r^2+(L^2\div 4)}{2r}$ where L is the length of the span.

The ring was propotioned and subdivided into 18 segments (s) so as to make $s\div h^3$ constant. The spacing is shown in table I . The loads are then computed by table II, the live load is placed over the half span to give bending moments , maximum or nearly maximum.

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TEMPERATURE STRESSES.

Sin ce the top of the arch is covered and the underside cannot be reached by the sun's rays, the changes in temperature do not affect the arch in most cases, an appreciable amount. If temperature stress are considered, the thrusts and bend ing moments on any section can be computed from the formula $H = \frac{E c l r e}{\Sigma y^2 - m\Sigma y} \quad \frac{Ic - e Is}{s}$ where

l = the span of the neutral surface.
c = the change of temperature of the ring in degrees Farh.
r = rate of expansion per degree Farh.
$m = (\Sigma_0^n y \quad) \div n$
n = number of divisions of the ring, "s" ;

The thrust on any section will be resultant of H perpendicular to that section, and the bending moment will be , $M = H \times (y - m)$.
Table IV gives the thrust and bending moments of several points of the ring for a change in temperature of 42°Farh.
Table V gives the final stresses per sq. in. in the ring at the crit-

ical points also the assumed and adjusted thicknesses. After finding the final stresses, the intensities of the stresses in all parts of the concrete and of the steel reinforcement are computed from Mr. Thacher's formulas $f_c = \frac{T}{Ac + ea} \pm \frac{6hM}{Ic + eIs}$ and $f_s = \frac{eT}{Ac + ea} \pm \frac{6eh'M}{Ic + eIs}$ in which

f_c = intensity of stresses in the concrete.
f_s = " " " " " steel.

T = thrust on section line 1" wide, in lbs.
A_c = area of section of concrete 1" wide, square inches.
$e = E_s \div E_c$ where E_s = modulus of elasticity of steel and
E_c = " " " " concrete.

a = area of steel per inch width $A_s \div b$, square inches.
h = depth of concrete in inches.
M = bending moment on section 1" wide ft. lbs.
I_c = moment of inertia of concrete, A_c, abo ut the neutral axis of the combination.
I_s = moment of inertia of steel, (a), about the neutral axis of the combination.
b = distance from center to center of steel members, in the direction of the width of the arch, inches

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h' =depth of steel in inches.

The computation of the stresses in the steel and concrete are found in table VI .

The total height of the spandrel wall will be 12 ft. at the springing . Supposing the earth fill to have an angle of repose of $26° 34'$ or a natural slope of 1 on 2, then the horizontal thrust

$$P = \frac{wx^2}{2}\left(\frac{1-\sin\phi}{1+\sin\phi}\right) \qquad w = 120 \text{ lbs, cu ft.} \quad x = 12' \quad \phi = 26° 34'$$

$$P = \frac{120 \times 144}{2} \times \left(\frac{1-.447}{1+.447}\right) = 3301.25 \text{ lbs.}$$

Bending moment at junction of spandrel wall and top of arch.

$$= 3301.25 \times \frac{x}{3} = 13205 \text{ ft. lbs.}$$

$$M = \frac{wl^2}{8} \qquad w = \frac{8M}{l^2} = \frac{13205 \times 8}{144 \times 12} = 61. \text{ lbs, sq. in.}$$

This stress is within the allowable limits and the wall will be 10″ thick at top and 13″ at bottom.

SPECIFICATIONS.

These consists of the portions of the structure indicated on the plans and which portions are either monolithic or of reinforced concrete. They embrace providing all materials and labor to construct and complete the work making and placing of forms, bending and placing of steel, mixing and placing of concrete , removal of forms, removing rubbish and finishing of surfaces.

FORMS:-,The forms should be of such a character that after they are removed all surfaces will be plain and level and have the proper elevations called for . Wherever a surface finish is to be used, rough lumber can be used on that side. The size, thickness, and quality of the lumber being left to the discretion of the contractor. The forms should not be removed until the concrete has become hard

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enough to sustain its own weight and the probable weight liable to be superimposed. Shores should be left in place at least four weeks. Before concreting , all forms should be cleaned of saw-dust, blocks shavings, dirt and dust, holes patched with tin , oiled and sprinkled.

CONCRETE:- The concrete is required to be mixed by volume; 1-3-6 being required for footings and foundations and 1-2-4 for structural members 1-2 mortar for finish and this should never be less tham 1/2 inch in thickness. Water enough to make a pasty mixture is required.

(Note - By 1-3-6 is meant 1 part cement, 3 parts sand, 6 parts by volume of broken stone or gravel.

CEMENT:- All cement used shall be Portland cement and shall be inspected either at the place of manufacture or on the work. In order to allow ample time for inspecting and testing, the cement shall be stored in a suitable weather-tight building, having the floor properly blocked or raised from the ground. The ce ment shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment. Every facility shall be provided by the contractor and a period of at least 12 days allowed for the inspection and necessary tests. Cement shall be delivered in suit - able packages with the brand and name of the manufacturer plainly marked thereon.

A bag of cement shall contain 94 lbs of cement net. Each barrel of Portland cement shall 4 bags of the above net weight. Cement failing to meet the seven days requirements may be held awaiting the results of the 28 day tests before rejection. All tests shall be made in accordance with the methods proposed by the committee on Uniform Tests of Cement of the American Society of Civil Engineers,

presented to the society January 21, 1903 and amended Jan. 20 1904, with all subsequent amendments thereto. The acceptance or rejection shall be based on the following requirements: Portland Cement: Definition : This term is applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly propotioned argillaceous and calcareous materials and to which no addition greater than 3% has been made subsequent to calcination.

SPECIFIC GRAVITY.

The specific gravity of the cement thouroughly dried at 100°C shall be not less than 3.10.

FINENESS.

It shall leave by weight a residue of not more than 8 % on the No. 100, and not more than 25% on the No. 200 seive.

TIME OF SETTING.

It shall develop initial set in not less than 30 minutes, but must develop hard set in not less than one hour, nor more than 10 hours.

TENSILE STRENGTH.

The minimum requirements for tensile strength for briquettes 1" square in section shall be within the following limits, and shall show no retrogression in strength within the periods specified:

NEAT CEMENT.

AGE	STRENGTH.
24 hours in moist air	150 - 200 lbs.
7 days (1 day in moist air, 6 days in water)	450 - 550 lbs.
28 days (1 day in moist air, 27 days in water)	550 - 650 lbs.

One part cement, three parts sand.

7 days (1 day in moist air, 6 days in water)	150 - 200 lbs.
28 days (1 day in moist air, 27 days in water)	200 - 300 lbs.

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CONSTANCY OF VOLUME.

Pats of neat cement about 3" diameter , 1/2" thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of 24 hours. (a) a pat is then kept in air at normal temperature and observed at intervals for at least 28 days . (b) Another pat is kept in water maintained as near 70° F. as practicable and observed at intervals for at least 28 days. (c) A third pat is exposed in any convenient way in an atmosphere of steam , above boiling water , in a loosely closed vessel for five hours. These pats, to satisfactorily pass the requirements, shall remain firm and hard and show no signs of distortion, checking, cracking or disintegrating.

SULPHURIC ACID AND MAGNESIA.

The cement shall not contain more than 1.75% of anhydrons sulphuric acid (SO_3) not more than 4% of magnesia (MgO).

SAMPLING.

The sample shall be a fair average of the contents of the package; it is recommended that, where these conditions permit , one barrel in evry 10 be sampled. All samples shall be passed through a seive having 20 meshes per linear inch in order to break up lumps and remove foreign matter; this is also a very effective method of mixing them together in order to obtain an average. For determining the characteristics of a shipment of cement, the individual sample may be mixed and the average tested; where time will permit , however, it is recommended that they be tested seperately.

METHOD OF SAMPLING.

Cement in barrels should be sampled through a hole made in the center of one of the staves, midway between the heads, or in the head by means of an auger or a sampling iron similar to that used by

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sugar inspectors. If in bags, it should be taken from surface to center.

SAND.

All sand shall be clean sharp sand, not having any excessive amount of foreign material in the form of loam or clay; 10 % can be allowed.

BROKEN STONE.

Stone should pass a 3/4 in. ring for small work, 1 1/2" for large work; screenings, if clean, are permitted. All stone should be free from dirt which mught keep the cement from adhering to the stone. Sandstone/ limestone, granite, traprock or other stone can be used.

GRAVEL.

Gravel should be not larger than that passing a 3/4" ring and shall contain no sand unless the portion of sand in the mixture used is reduced. It shall also be free from clay, loam and other extraneous material.

MIXING AND PLACING.

The mixing can either be done by hand , the cement, sand and stone being placed on a water tight mixing board, or mixed in a batch mixer The propotion of water determined according to the nature of the materials being mixed, to give same a good, pasty, well mixed consistency. The concrete shall be handled quickly and brought to the points of placing by hoists, derricks, concrete buggies or wheelbarrows, proper runs being supplied so that the steel may not be displaced. No concrete that has begun to show signs of set shall be used.

WATERPROOFING.

The top of the arch and the sides of the spandrel walls shall be

w aterproofed with 1/2" coating of cement mortar consisting of 1 part cement to two parts of sand and average shall be provided at the haunches by means of an unglazed clay pipe reaching diagonally from the center of the space over the abutment to the soffits of the arch. through whivh it projects about an inch. The surface of the abutment is dished toward the upper end of the pipe, which is covered with wire netting to exclude coarse material and a bed of broken stone is laid over all to receive the earth fill.

SPANDREL WALL AND PARAPET WALLS.

THe spandrel wall shall be made of 1-2-4 concrete and shall be connected to the cornice by parapet walls by means of an anchor bolt 1" square and five ft. long as shown in plans.

The cornice is to be of 1-2-4 concrete and made in seven foot sections and laid in sections like cut stone.

The parapet wall shall consist of concrete posts 8" x 12" of 1-2-4 concrete and shall be moulded on the bolt from the spandrel wall as shown in plans. A hand rail of wrought iron pipe 2" internal diameter shall be provided and moulded into the parapet wall. The hand rail shall enter the smallest dimension of the posts, and to a depth not less than four inches. All joints between the arch ring, spandrel walls, cornice, and parapet walls, shall be filled with cement mortar of a consistency of 1-2.

REINFORCEMENT.

All steel shall be medium steel, having an ultimate tensile strength of from 6 0,000 to 68,000 lbs per sq.in. and an elastic limit of not less than 1/2 the ultimate strength and should elongate not less than 22% in 8" and bend cold 180° around a diameter equal to the

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thickness of the piece tested without fracture on the outside of bend.

The I-beams used shall be riveted at the abutments to a 5"x5"x1/2" angle iron extending along the entire length of the abutment and embedded therein. All reinforcement shall be not less than 3 in. from the exposed surface of the concrete.

Signed James A. Megahy
April 1st 09"

TABLE I.

Point	First Trial h	First Trial h^3	First Trial s	2nd Trial s	3rd Trial s (Correct)
1	2.50	15.62	11.25	10.46	10.75
2	2.37	13.31	9.58	8.91	9.05
3	2.11	9.39	6.76	6.29	6.38
4	1.82	6.02	4.33	4.03	4.09
5	1.70	4.91	3.53	3.28	3.38
6	1.62	4.25	3.06	2.84	2.89
7	1.58	3.94	2.83	2.63	2.67
8	1.55	3.72	2.67	2.49	2.52
9	1.52	3.51	2.52	2.35	2.38

TABLE II.

Points	Length ft.	Ring 150 LBS. cu. ft. Depth ft.	Ring LBS.	Fill 120 LBS. cu. ft. Depth ft.	Fill LBS.	Pavement 12" deep 150 LBS. cu. ft.	$16\frac{2}{3}$ ft. Width of Track 25 LBS. sq. ft.	Total Dead Load LBS.	Live Load LBS.	Total LBS.	Summation LBS.
1	10.75	2.50	9909	10.12	10486	1110	231	21736		21736	21736
2	9.05	2.37	3146	6.75	6805	991	206	11148		11148	32884
3	6.38	2.11	2009	4.87	3525	705	146	6385		6385	39269
4	4.09	1.82	1141	4.00	1849	450	93	3533		3533	42802
5	3.38	1.70	867	3.70	1462	390	81	2800		2800	45602
6	2.89	1.62	706	3.60	1178	330	68	2282		2282	47884
7	2.67	1.58	632	3.45	1035	300	62	2029		2029	49913
8	2.52	1.55	582	3.35	904	270	56	1812		1812	51725
9	2.38	1.52	534	3.10	803	255	53	1650		1650	53375
Total			19531		28047	4801	996	53375		53375	
10								1650	229	1879	1879
11								1812	235	2047	3926
12								2029	270	2299	6225
13								2282	297	2579	8804
14								2800	351	3151	11955
15								3533	405	3938	15893
16								6385	634	7019	22912
17								11148	889	12037	34949
18								21736	1000	22736	57685
Total								53375	4310	57685	
Grand Total								106750	4310	111060	

H = 54000 LBS.

TABLE III.

Point	Ordinates Arch	Equilibrium Polygon Ordinates	Equilibrium Polygon Lever Arms	Equilibrium Polygon Moments	Triangles Ordinates	Triangles Moments	Ordinates for Closing Line (m p m')	Ordinates for Closing Line (k a k')	Ordinates for Deflection Polygons (both sides) Arch	Ordinates for Deflection Polygons (both sides) Equil. Poly.	True Ordinates Col. 8 x C/C	Measure of moment Difference of Cols 9 & 12	Moments Ft. lbs. Col. 13 x H	Thrusts
V	0.00	0.00					−(13.46)	(−8)			−(8.64)	−.64	−53568	100875
1	2.33	4.87	4.62	22.49	.77	3.61	−8.69	−5.63	−11.26	−17.45	−5.57	+.06	+5.22	90375
2	4.75	10.37	13.50	139.99	2.26	30.64	−3.15	−2.12	−15.50	−23.98	−2.02	+.10	+8370	86250
3	7.75	13.25	20.62	273.21	3.46	71.38	−.36	−.25	−16.00	−24.85	−.23	+.02	+1674	84750
4	8.75	14.62	25.50	372.81	4.28	109.14	+1.13	+.87	−14.26	−22.82	+.72	−.15	−12555	84375
5	9.25	15.33	28.91	443.19	4.85	141.20	+1.82	+1.37	−11.52	−19.39	+1.16	−.21	−17577	83625
6	9.63	15.75	31.87	501.95	5.35	170.55	+2.21	+1.63	−8.40	−15.16	+1.41	−.22	−18414	83600
7	9.88	15.91	34.41	547.46	5.78	194.94	+2.43	+1.87	−4.52	−10.43	+1.55	−.32	−26784	
8	10.00	16.12	36.87	594.34	6.17	228.28	+2.50	+2.00	−.52	−5.31	+1.60	−.40	−33480	
9	10.08	16.16	39.08	631.53	6.56	256.36	+2.68	+2.04	00.00	00.00	+1.72	−.32	−33480	83800
10	10.08	16.08	41.25	663.30	6.93	285.86	+2.63	+2.04			+1.70	−.34	−28458	
11	10.00	16.00	43.50	696.00	7.30	317.55	+2.62	+2.00			+1.68	−.32	−26784	
12	9.88	15.75	45.87	722.45	7.70	353.27	+2.28	+1.87			+1.57	−.36	−30132	83437
13	9.63	15.50	48.50	751.75	8.14	394.79	+2.04	+1.63			+1.30	−.33	−27621	83625
14	9.25	15.00	51.37	770.55	8.63	443.41	+1.61	+1.37			+1.03	−.34	−28458	84000
15	8.75	14.25	54.83	781.32	9.21	504.48	+.90	+.87			+.57	−.30	−25110	84375
16	7.75	12.83	59.62	764.92	10.01	596.89	−.51	−.25			−.32	−.07	−5859	84750
17	4.75	9.87	66.75	658.82	11.21	748.26	−3.38	−2.12			−2.16	−.04	−3348	86062
18	2.33	4.66	75.66	352.57	12.71	962.76	−8.76	−5.63			−5.62	+.01	+837	89250
V'	0.00	0.00					−(13.39)	−(8.00)			−(8.59)	−.59	−49383	99187
Summation	144.84	242.32		9688.65	121.32	5813.87								

TABLE IV.

"H" due to temperature = 796.32 lbs				
Point	Moment	Thrust	Total Moment	Total Thrust
"V"			53568	100875
1	4722.97		9744	90375
4	503.00		13058	84375
6	1080.42		19534	83500
10	1150.00	Negligible	29508	83400
12	1319.50		31451	83437
15	503.00		25613	84375
18	4722.97		5559	89250
"V'"			49383	99187

TABLE V.

Point	"T" for 1" width	"M" for 1" width	Trial Thickness ft	Adjusted Thickness ft
"V"	8406	4464		3.33
1	7531	812	2.50	3.16
4	7031	1088	1.82	2.29
6	6966	1624	1.62	2.04
10	6950	2459	1.52	1.92
12	6958	2620	1.58	1.99
15	7031	2134	1.82	2.29
18	7437	463	2.50	3.16
"V'"	8265	4115		3.33

TABLE VI.

$E_s = 29000000$

$E_c = 1933333$

$e = 15$

$f_c = \dfrac{T}{A_c + ea} \pm \dfrac{6hM}{I_c + eI_s}$

12" $31\frac{1}{2}$ lb. I. beam   spacing = 30" c.-c.

$a = \dfrac{9.26}{30} = .308$

$ea = 4.62$

$I_s = \dfrac{215.8}{30} = 7.19$

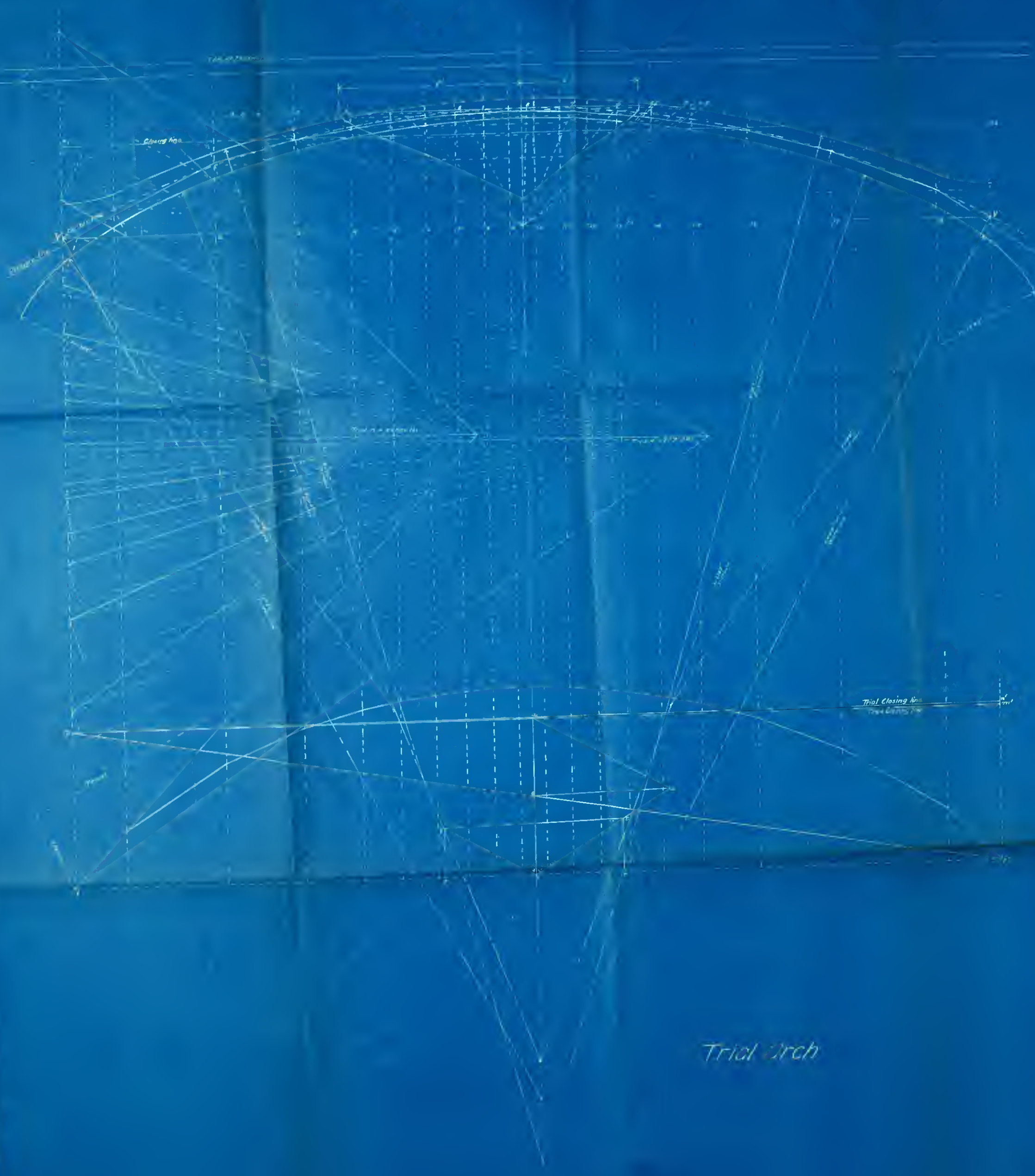
$EI_s = 107.85$

$f_s = \dfrac{eT}{A_c + ea} \pm \dfrac{6eh'M}{I_c + eI_s}$

Allowable unit stress in Concrete = [compression = 550 lbs. □" ; tension = 65 lbs. □"]

Point	Area of Section inches = h×1	$I_c = \frac{h^3}{12}$	f_c lbs. □"	f_s lbs. □"
1	37.92	4543	$f_c = \left[\frac{7531}{37.92+4.62} \pm \frac{6\times812\times37.92}{4543+107.85}\right] = (176 \pm 39) = +225,\ +137$	$f_s = 15\left[\frac{7531}{37.92+4.62} \pm \frac{4872\times12}{4543+107.85}\right] = (177 \pm 12)\,15 = +2825,\ +2475$
4	27.48	1729	$f_c = \left[\frac{7031}{27.48+4.62} \pm \frac{6\times1088\times27.48}{1729+107.85}\right] = 219 \pm 97 = +316,\ +122$	$f_s = \left[219 \pm \frac{6486\times12}{1836.85}\right]\times15 = (219 \pm 42)\,15 = +3915,\ +2655$
6	24.48	1222.5	$f_c = \left[\frac{6966}{24.48+4.62} \pm \frac{6\times24.48\times1628}{1222.5+107.85}\right] = (239 \pm 18) = +257,\ +221$	$f_s = \left[239 \pm \frac{6\times1628\times12}{1222.5+107.85}\right]\times15 = (239 \pm 8.8)\,15 = +3720,\ +3430$
10	23.	1014	$f_c = \left[\frac{6950}{23+4.62} \pm \frac{6\times2459\times23}{1014+107.85}\right] = 251 \pm 298 = +549,\ -47$	$f_s = \left[251 \pm \frac{19170\times12}{1121.85}\right]\times15 = (251 \pm 157)\,15 = +6120,\ +1410$
12	23.88	1134.8	$f_c = \left[\frac{6958}{23.88+4.62} \pm \frac{6\times2620\times23.88}{1134.8+107.85}\right] = 243 \pm 303 = +546,\ -60$	$f_s = \left[243 \pm \frac{15720\times12}{1242.65}\right]\times15 = (243 \pm 151)\,15 = +5910,\ +1380$
15	27.48	1729	$f_c = \left[\frac{7031}{27.48+4.62} \pm \frac{6\times2134\times27.48}{1729+107.85}\right] = 219 \pm 191 = +410,\ +28$	$f_s = \left[219 \pm \frac{6\times2134\times12}{1729+107.85}\right]\times15 = (219 \pm 83)\,15 = +4530,\ +2040$
18	37.92	4543	$f_c = \left[\frac{7437}{37.92+4.62} \pm \frac{6\times463\times37.92}{4543+107.85}\right] = 174 \pm 22 = +196,\ +152$	$f_s = \left[174 \pm \frac{2778\times12}{4650.85}\right]\times15 = (174 \pm 7)\,15 = +2715,\ +2490$
V'	40	5333.33	$f_c = \left[\frac{8406}{40+4.62} \pm \frac{6\times4464\times40}{5333.33+107.85}\right] = 188 \pm 196 = +384,\ -8$	$f_s = \left[188 \pm \frac{26784\times12}{5441.18}\right]\times15 = (188 \pm 59)\,15 = +3705,\ -1935$

6.17	228.28	+2.50	+2.
6.56	256.36	+2.68	+2.
6.93	285.86	+2.63	+2.
7.30	317.55	+2.62	+2.
7.70	353.27	+2.28	+1.8
8.14	394.79	+2.04	+1.6
8.63	443.41	+1.61	+1.3
9.21	504.98	+ .90	+ .8
10.01	596.89	− .51	− .25
11.21	748.26	− 3.38	− 2.12
12.71	962.76	− 8.76	− 5.6
		−(13.39)	(−8.00
121.32	5813.87		



Trial Arch

PLATE 1.

Loading

Points	Length ft	Ring 150 lbs. cu ft Depth ft	Ring 150 lbs. cu ft lbs.	Fill 120 lbs. cu ft Depth ft	Fill 120 lbs. cu ft lbs.	Pavement 12" deep 150 lbs cu ft	Track 25 lbs. sq ft	Total Dead load lbs.	Live load lbs.	Total lbs.	Summation lbs.
1	10.75	2.50	9969	10.12	10486	1110	231	21736		21736	21736
2	9.05	2.37	3146	6.25	6805	991	206	11148		11148	32884
3	6.38	2.11	2009	4.67	3525	705	146	6385		6385	39269
4	4.09	1.82	1141	4.00	1849	450	93	3533		3533	42802
5	3.30	1.70	867	3.70	1462	390	81	2800		2800	45602
6	2.89	1.62	706	3.60	1178	330	68	2282		2282	47884
7	2.67	1.58	632	3.45	1035	300	62	2029		2029	49913
8	2.52	1.55	582	3.35	904	270	56	1812		1812	51725
9	2.38	1.52	539	3.10	803	255	53	1650		1650	53375
Total			19531		28047	4801	996	53375		53375	
10	2.38							1650	229	1879	1879
11	2.52							1812	235	2047	3926
12	2.67							2029	270	2299	6225
13	2.89							2282	297	2579	8804
14	3.30							2800	351	3151	11955
15	4.09							3533	405	3938	15893
16	6.38							6385	634	7019	22912
17	9.05							11148	889	2037	34949
18	10.75							21736	1000	22736	57685
Total								53375	4311	57685	
Sum total								106750	4310	111060	

H = 54000 lbs. Scale 6000 lbs. = 1"

Point	Ordinates Arch	Equilibrium Polygon Ordinates	Equilibrium Polygon Lever arms	Equilibrium Polygon Moments	Triangles Ordinates	Triangles Moments	Ordinates for Closing line (mp m')	Ordinates for Closing line (K'o K")	Ordinates for Deflection Polygon Arch	Ordinates for Deflection Polygon Equilibrium Polygon	True Ordinates	Measure of Moments Difference	[illegible]	Thrusts
							$-(13.40)$	(-8)			(-8.64)	$-.64$	-53568	100875
V	0.00	0.00												
1	2.33	4.87	4.62	22.49	.77	3.61	-8.64	-5.63	-11.26	-17.65	-5.57	$+.16$	$+5022$	98375
2	4.75	11.37	13.50	139.99	2.26	30.64	-3.15	-2.12	-15.50	-23.98	-2.82	$+.10$	$+3370$	86250
3	7.75	13.25	20.62	273.21	3.46	71.38	$-.36$	$-.25$	-16.00	-24.85	$-.27$	$+.02$	$+1674$	84750
4	8.75	14.62	25.50	372.81	4.28	109.14	$+1.13$	$+.87$	-14.36	-22.02	$+.72$	$-.15$	-12555	84375
5	9.25	15.33	28.91	443.19	4.85	141.20	$+1.82$	$+1.37$	-11.52	[illegible]	$+1.16$	[illegible]	[illegible]	83625
6	9.63	15.75	31.87	501.95	5.35	170.55	$+2.21$	$+1.83$	-8.40	-15.16	$+1.41$	$-.22$	-18914	83600
7	[illegible]	15.91	34.41	545.46	5.78	194.94	$+2.45$	$+1.87$	-4.52	-10.43	$+1.55$	$-.32$	-26784	
8	10.00	16.12	36.87	594.34	6.17	220.20	$+2.50$	$+2.00$	-5.52	-5.31	$+1.60$	$-.40$	-33400	
9	10.05	16.16	39.08	631.53	6.56	256.36	$+2.68$	$+2.04$	00.00	00.00	$+1.72$	$-.32$	-33400	83800
10	10.08	16.08	41.25	663.30	6.93	285.86	$+2.67$	$+2.04$			$+1.70$	$-.34$	-28458	
11	10.00	16.00	43.50	696.00	7.30	317.55	$+2.42$	$+2.00$			$+1.68$	$-.32$	-26784	
12	9.88	15.75	45.87	722.45	7.70	353.27	$+2.30$	$+1.87$			$+1.51$	$-.36$	-30132	83437
13	9.63	15.50	48.50	751.75	8.14	394.79	$+2.04$	$+1.43$			$+1.30$	$-.33$	-27621	83625
14	9.25	15.00	51.37	770.55	8.63	443.41	$+1.61$	$+1.37$			$+1.03$	$-.34$	-28458	84000
15	8.75	14.25	54.83	781.32	9.21	504.98	$+.90$	$+.87$			$-.57$	$-.30$	-25110	84375
16	7.75	12.83	57.62	764.92	10.01	546.89	$-.51$	$-.25$			$-.32$	$-.07$	-5859	84750
17	4.75	9.87	66.75	658.82	11.21	748.26	-3.38	-2.12			-2.16	$-.04$	-3348	86062
18	2.33	4.66	75.66	352.57	12.71	962.76	-8.76	-5.63			-5.62	$+.01$	$+837$	89250
V'	0.00	0.00					$-(13.39)$	(-8.00)			-8.59	$-.59$	-49383	99187
	144.84	242.32		9680.65	121.32	5613.87								

THESIS

Trial Arch for the design of a Reinforced Concrete Arch

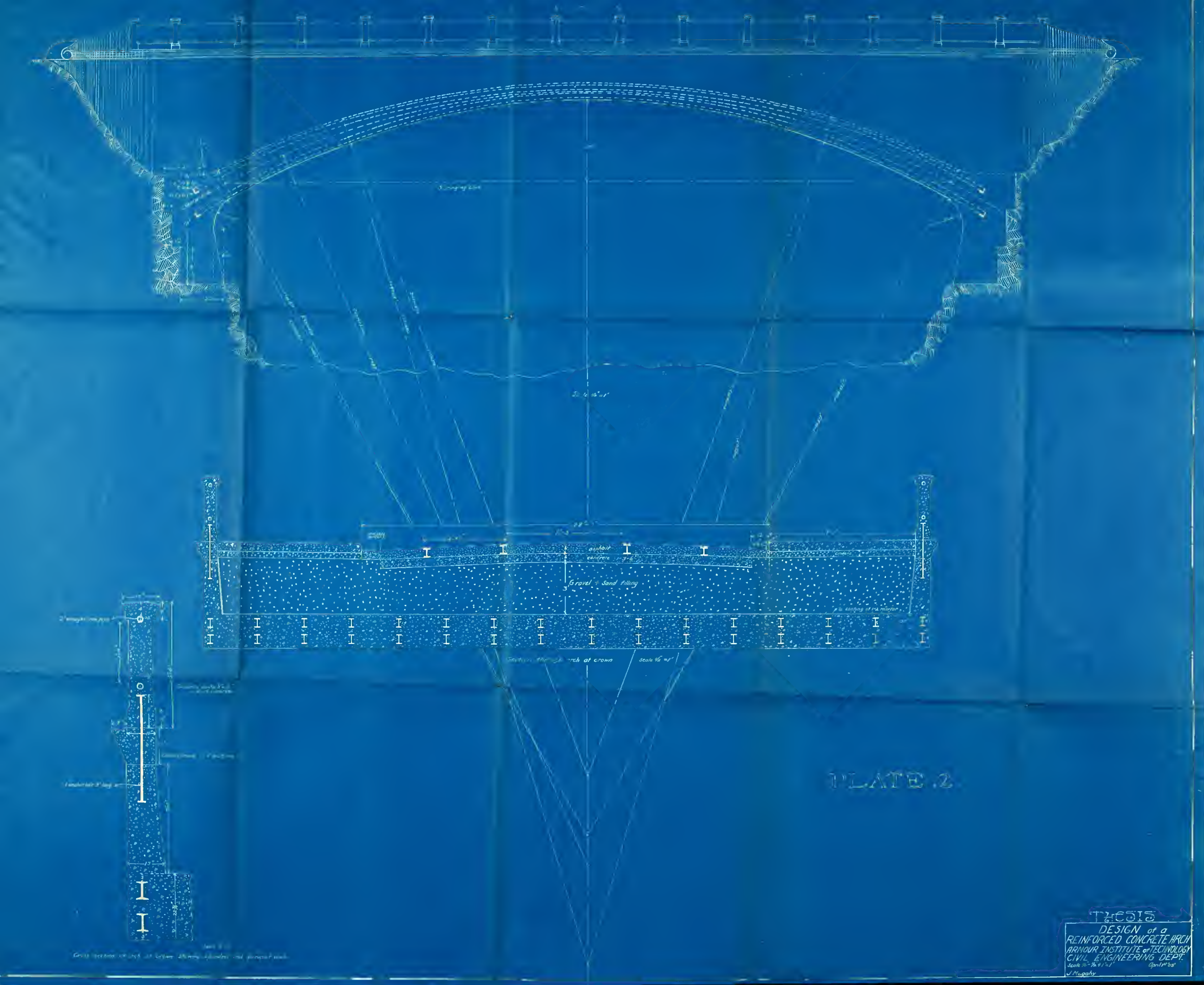
Armour Institute of Technology
Civil Engineering Dep't
J. [illegible]

THESIS

DESIGN of a
REINFORCED CONCRETE ARCH
ARMOUR INSTITUTE of TECHNOLOGY
CIVIL ENGINEERING DEPT.

Scale ¼"–½" = 1'   Apr. 1st '09

J. Mcgahy



asphalt
concrete
Gravel + Sand filling
arch at crown
PLATE 2
THESIS
DESIGN of a
REINFORCED CONCRETE ARCH
ARMOUR INSTITUTE of TECHNOLOGY
CIVIL ENGINEERING DEPT.
J Mcgahy